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Refractory coating based on cordierite for application in new evaporate pattern casting process

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Abstract

Standard raw materials, kaolin, talc, MgO, alumina, feldspar and sepiolite, were used in synthesis of four different cordierite type ceramics. Sintered cordierite was used as refractory filler in the ceramic coating for evaporative polystyrene patterns in the EPC process. The cordierite samples were tested by the following methods: roentgen diffraction analysis, diffraction thermal analysis and polarized microscope. The shape and grain size were analyzed by the program package OZARIA 2.5. In order to evaluate the possible application of cordierite as the refractory filler, four different coating processes were investigated.

Key words : D. Cordierite; Refractory coating; Evaporate pattern casting process; Quality of casting

1. Introduction

In order to achieve qualitative and profitable castings' production by the evaporate pattern casting process it is necessary to reach the balance in the system: evaporable polymer pattern–liquid metal–refractory coat–sandy cast in the phases of metal pouring, decomposition, evaporation of polymer pattern and formation and solidification of castings (Fig. 1). That requires systematical researches on complex appearances and processes occurring in pattern, metal and cast as well as on appearances and processes in contact zone metal–pattern, metal–refractory coat–sand [1–7].

During the casting, forming and solidification of the cast, the basic role of coat is creation of an efficient refractory barrier between sandy mould and liquid metal. Investigating the coat properties, it was determined that refractory coat has an insulation effect that reduces the cooling rate of liquid metal in a mould, which is the critical parameter for forming the castings structure. This is particularly distinctive for the complex casting conditions such as in EPC process. With this process, patterns and pouring systems made of polymers are held within the mould. When, getting in touch with liquid metal, polymers degrade and evaporate; at the same time, castings crystallization process is preformed. Polymer pattern degradation in contact with liquid metal is an endothermic process, so that castings structure forming is carried out in the sub-cooling conditions. If sub-cooling is significant, a fine, tiny-grained castings structure is formed. Castings structure and properties depend on a number of process parameters, such as casting temperature, polymer pattern density, type and size of sand grains used for moulding (i.e. permeability of moulding sand), construction of castings and pouring systems. These parameters were examined in co-relation with the properties of cordierite-based refractory coatings. All of these data point to complexity of castings solidification conditions achieved by EPC method as well as to necessity to determine the co-relation between casting process parameters and structure and properties of the cast. The required coating properties (refractoriness, favorable gas permeability, easy application and adhesion to sand mould surfaces and polymer pattern surfaces, easy controlling the thickness of the coating layer and high drying rate without cracking or removal of the dried coating layers) were achieved by optimization of coating composition and their production technology [1–7].

Refractory coatings for application in EPC process must satisfy a number of specific demands as follows:

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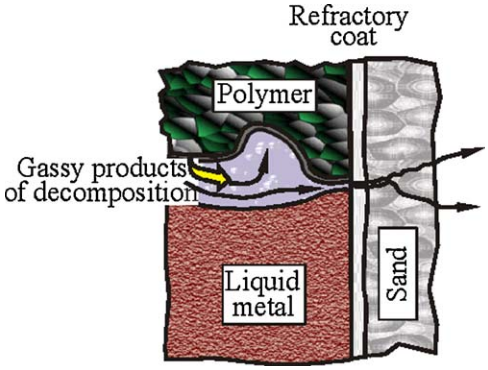

Fig. 1. System balance: liquid metal–refractory coat–pattern–sand [2].

- Corresponding coat refractoriness,
- Permeability should be compatible to that of sand which is used for mould making (highly permeable coat is used for rougher sand while medium and low permeable coat are used for finer sand),
- Quick drying,
- Dried layer should be visible on the pattern,
- There should be a possibility to control and adjust coat layer thickness,
- Appropriate strength, resistance to abrasion, resistance to cracks during storage, resistance to bending and deformation during mould making,
- If rougher sand and high casting temperatures are used for mould making, then the refractory coating layer should be thicker [8–10].

Most modern refractory coatings represent complex mixture of over 15 components. Four basic components are refractory filler, liquid carrier solvent, binders and agents for maintaining suspension.

As a refractory coating filler, cordierite was chosen due to its properties:

- Low thermal expansion coefficient,
- Relatively high melting point,
- Does not react with liquid metal,
- Does not produce gases when in contact with liquid metal [11–17]

An important coating property is the sediment stability of coating suspension. Different kinds and quantities of additives were examined with an aim to enable easy additive adsorption on the refractory filler particles, maintain filler in a dispersed state and to prevent filler precipitation.

A binding agent for the coating was chosen with regard to the size and shape of the refractory filler particles in order to enable connection between the particles and to provide good adhesion of refractory particles to the observed surface of polymer pattern. Water was used as a liquid solvent. The optimal density of refractory coating was 2000 kg/m^3 [18–19].

2. Experimental procedure

The cordierite for foundry coating production was obtained by high temperature reaction in solid state, wherein MgO, kaolin, alumina, talc, feldspar and sepiolite were used for synthesis (Table 1).

Chemical composition, loss ignition and color of starting compounds for cordierite production are shown in Table 2.

The starting materials for cordierite mass, except kaolin, were ground to 1×10^{-4} m grain size, then mixed in the ratio: $2MgO:2Al_2O_3:5SiO_2$. After homogenization, the powder mixture was pressed on Lais-type press, under 1×10^6 Pa pressure, and then sintered at 1300 °C for 8 h in laboratory oven in oxygen atmosphere. The cordierite samples were tested by the following methods:

- Roentgen diffraction analysis was used for determination and monitoring of phase composition. It was performed on

Table 1
Starting composition of mixtures for cordierite samples preparation.

Sample	Compound type (wt%)					
	MgO	Kaolin	Alumina	Talc	Sepiolite	Feldspar
A	/	37	35	/	28	/
B	/	29	35	36	/	/
C	14	37	49	/	/	/
D	/	28	23	45	/	4

Table 2
Chemical composition, loss ignition and color of starting components for cordierite production (wt%).

Component	Loss ignit.	Fe_2O_3	Al_2O_3	SiO_2	CaO	MgO	Na_2O	K_2O	Color
Kaolin	8.14	1.34	28.83	53.0	0.50	/	0.2	0.3	Beige
Talc	5.3	0.28	1.18	60.15	1.50	51.40	/	/	White
Feldspar	0.36	0.035	18.39	67.74	/	0.36	0.66	12.37	White
Alumina	3.15	0.09	95.96	0.14	0.16	0.00	0.15	0.1	Rosy
Sintermagnesite	0.52	1.18	0.10	2.36	1.57	94.27	0.1	0.1	White
Sepiolite	18.3	0.08	0.00	52.33	0.44	28.25	0.03	0.14	White

Table 3
Parameters of EPC process.

No.	Parameter	Parameter description
1.	Tested alloy	AlSi10Mg
2.	Preparation methods of liquid metal	-Refinement by compounds based NaCl and KCl in quantity of 0.1 wt% on melt mass; -Degasification by briquette C_2Cl_6 in quantity of 0.3 wt% on melt mass; -Modification by sodium in quantity of 0.05 wt%
3.	Casting temperature	720 °C
4.	Evaporable polystyrene pattern	-Density: 18 kg/m^3 -Pattern construction: plate (0.2 × 0.05 × 0.02) m -Polystyrene grain size 1–1.5 × 10^{-3} m
5.	Mounting pattern for casting	"Cluster" with four patterns-plates set on central runner gate
6.	Gating of moulds	-Central runner gate (0.04 × 0.04 × 0.4) m, -Ingates (0.02 × 0.02 × 0.01) m, 2 pieces
7.	Dry quartz sand for cast production	Grain size: 2.6 × 10^{-4} m

Table 4
Parameters of production process of cordierite-based refractory coatings for casting applications.

No.	Process parameters
1.	Composition of refractory coating: -refractory filler: cordierite with grain size of 40 μm, 92–94 wt% -binding agent (wt%): bentonite 1.5–2.5; bindal H 0.5–1 -suspension maintenance agent (wt%): $Na_3P_3O_3$ 1–3; carboxymethylcellulose (CMC) 0.5–1 -solvent: water
2.	Coating suspension density: 2000 kg/m^3
3.	Coating suspension temperature: 25 °C
4.	Slowly coat mixing in tank during the coat applying on pattern–velocity 1 revolutions/min
5.	Methods of coat applying on pattern: "cluster" immersion into tank with coat; overflowing; coating with brush
6.	The method to eliminate the suspension excess from the model after take out from the cladding tank: models are squeezed, in vertical position for 5–10 s; they are then inclined under the angle of 45° for 5 s in order for the suspension layers to get even on the model surface
7.	Air drying of water-based coatings: first layer 2 h; final layer 24 h
8.	Coating layer thickness on models after drying: 5–7 × 10^{-4} m

Röntgen diffractometer Philips PW 1710 with curved graphite monochromator and scintillometer, 40 × 10^3 V tube voltage, 30 × 10^{-3} A power, samples tested in the range of 4–65° 2θ;
- Diffraction thermal analysis on SHIMADZU DTA-50 device, in the temperature range 10–1200 °C, with the 10 °C/min heating rate, aimed at testing characteristic temperatures at which solid state reaction in the three component system of $MgO–Al_2O_3–SiO_2$ was carried out;
- Quality mineral analysis of the samples was carried out under polarizing microscope for reflected and transparent light, of type JENA POL-U, Carl Zeis Jena, by immersion method, with qualitative identification of present minerals, magnification 10–50×. The analyses of shape and grain size were done by the program package OZARIA 2.5 (0–1 range), shape factor for 0 – section corresponding to needle shape, for 1 – section corresponding to circle, grain size given in microns (10^{-6} m).

During the application of coating suspension, adhesion to the pattern surface was evaluated and dried coating tested for bubbles, peeling, cracking, resistance to abrasion and wiping off. After being dried, the coated patterns were placed into steel moulds and covered with dry, free quartz sand of 2.6 × 10^{-4} m grain size. Casting was carried out after moulding.

The parameters of the EPC process are presented in Table 3. Overview of optimal process parameters for production and preparation of coat, lining and coat drying on polystyrene patterns are shown in Table 4.

3. Results and discussion

The chemical compositions of cordierite samples applied for manufacture of coatings are shown in Table 5. The appropriate roentgenograms of samples from A to D are given in Fig. 2. The traces of cordierite were poorly evident in sample A (Fig. 2a). Beside sepiolite and quartz, other present crystal phases were not identified with assurance. In samples B and C (Fig. 2b and c), within the dominant presence of cordierite, spinel and quartz

Table 5
The chemical compositions of cordierite samples.

Designation	The chemical composition (wt%)				
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
A	55.63	28.59	1.44	4.06	9.88
B	55.97	27.89	2.21	5.80	9.13
C	43.52	30.10	1.23	3.76	20.80
D	46.20	28.0	2.40	6.18	15.1

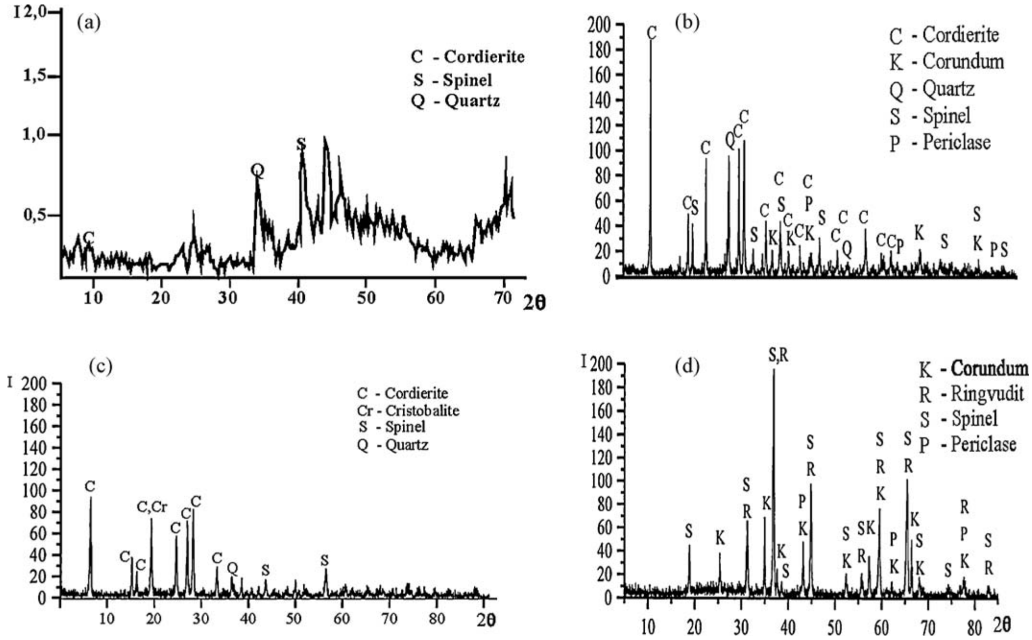

Fig. 2. Diffraction-meters of powder of the samples A–D.

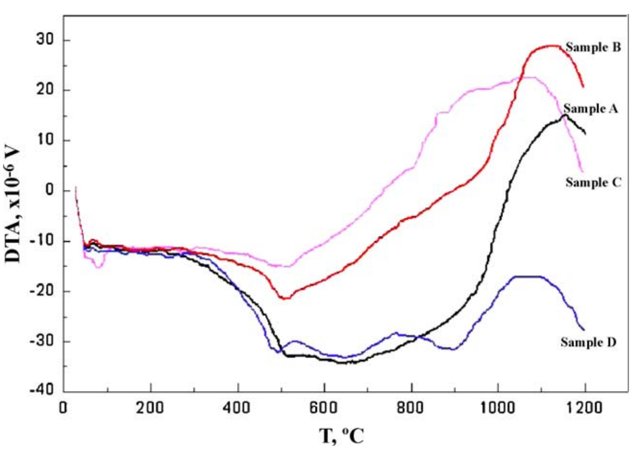

Fig. 3. DTA curves of samples A–D.

were present, too. In the sample B crystal phases of corundum and periclase were identified, while in sample C cristobalite was identified. Sample D was without cordierite, the most common present phases were corundum, spinel, ringvudit and periclase.

Therefore, in the further experiments, samples B and C were chosen as the refractory fillers for the coating production in the EPC process.

By analyzing the DTA diagrams it is possible to notice the characteristic temperatures of endothermic and exothermic effects during heating (Fig. 3). The endothermic effect corresponds to the phase transformation α-tridimit → α-quartz (at 493–517 °C), while the exothermic effect corresponds with the reaction between MgO and SiO_2, whereby magnesium metasillicate is obtained (at 1069–1155 °C). DTA curves for the A–C samples differ from the curve for the samples D, where

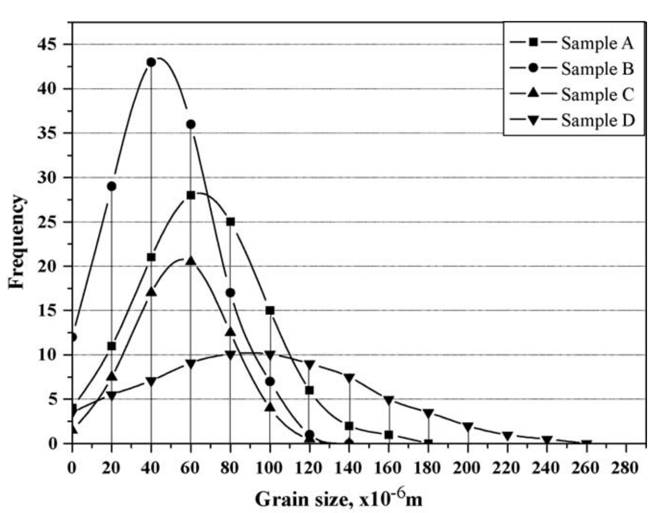

Fig. 4. Histogram of grain size of samples A–D.

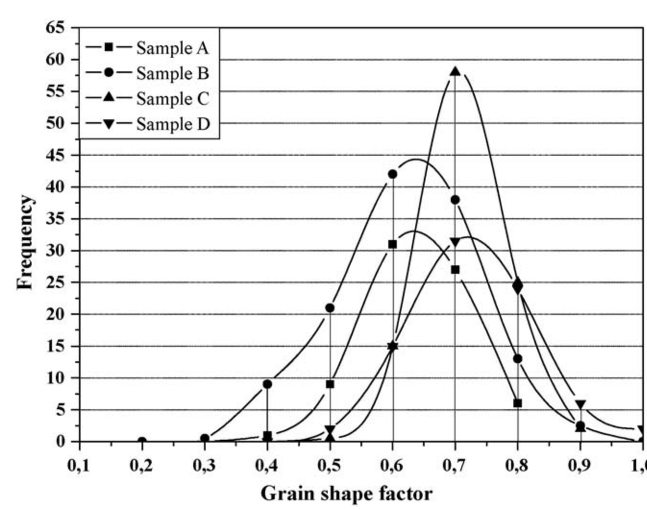

Fig. 5. Histogram of grain shape factor of samples A–D.

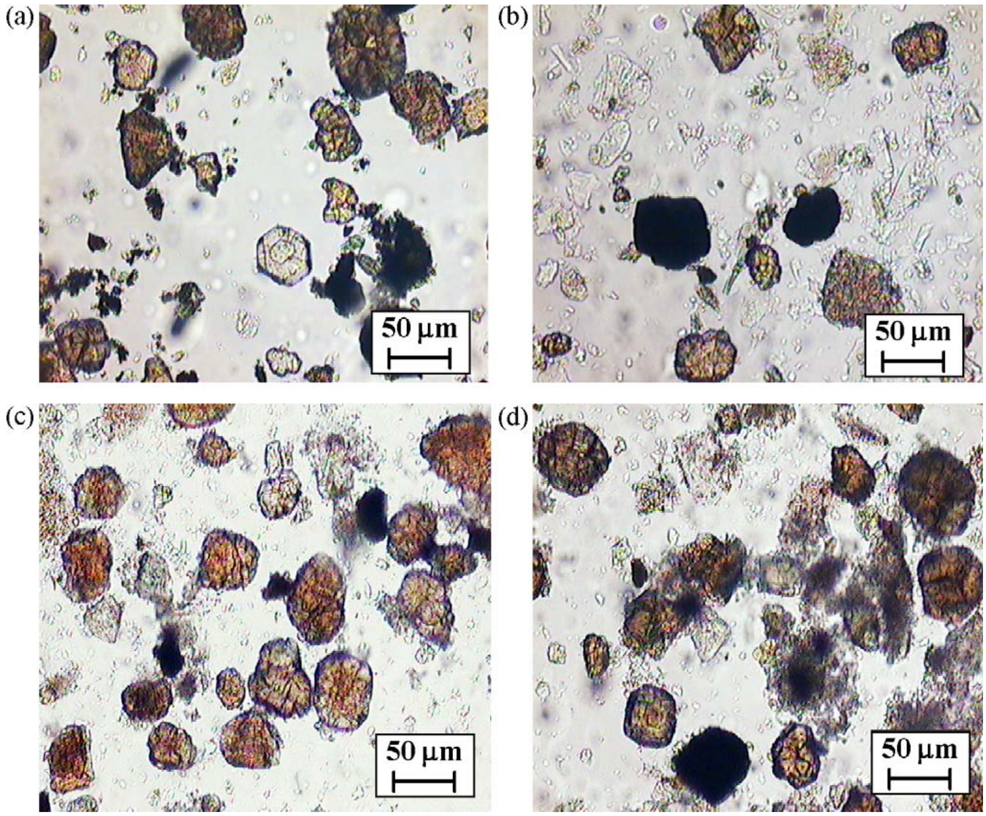

Fig. 6. Microphotographs of samples A–D.

two exothermic effects are present. We assume that the second exothermic peak is a result of the crystallization of spinel. Endothermic effect appearing at low temperatures (up to 150 °C) is consequence of desorption of physically bounded water.

With respect to the application of powders as refractory fillers, variation in grain size is favorable. Different particles size fits better and form uniform coating layer on the pattern surface. Histograms of different grain size and grain shape factors for samples A–D, are shown in Figs. 4 and 5. The average grain size was 44.4×10^{-6} m, the average grain shape factor was 0.63, which means that the grains are rounded.

In Fig. 6, microphotographs of suspensions of samples A–D are shown. The microphotograph shows the presence of tiny, irregular particles of cordierite, rather uniformly distributed in solvent.

The examinations of synthesis, characterization and application of refractory coatings based cordierite showed that sediment stability of coating suspension was crucial quality parameter. Distribution homogeneity of refractory filler in coating suspension depends on suspension preparation and coating procedure. Continuously slow mixing, controlling the density (2000 kg/m^3) and keeping the constant temperature (22°), were necessary.

The applied and dried coating layers, B and C, on the patterns, did not crack, peel, nor wipe off. After casting and shaking out castings from the patterns, the coating was easily removed from the surface of castings. The produced castings had smooth and bright surface and they were the exact replicas of used patterns. This means that selected casting temperature (720 °C), coating thickness (5×10^{-4} m) and pouring of moulds, produced equilibrium in the system: evaporative pattern – refractory coating – liquid metal – sand. At the same time the casting process was carried out uniformly, without stoppage zones, without cracking and metal penetration into sand. The surface of castings was bright and clean. Testing mechanical and structural properties of the castings, series B and C, showed that there were no substantial differences in the results and that they corresponded to the values, which are standard for this type of alloy.

4. Conclusion

The characteristic of cordierite ceramics to have low thermal expansion coefficient ($\alpha = 2.1$–2.5×10^{-6} K^{-1}) makes it interesting for application as ceramic coatings in the EPC process. There is reduced risk of coating cracking with temperature changes during the pouring of liquid metal, formation and crystallization of castings. Taking into consideration that cordierite has high refractoriness; its application should be extended even to the alloys casted at temperatures up to 1200 °C. In that sense, the application of cordierite coating in the EPC process showed positive effects.

During application to polystyrene pattern, the coating flows evenly, i.e. it is easily spread by brush. The coating layers are of continuous thickness all over the pattern surface. This provides uniform solidification of entire casting volume and fast elimination of the pattern decomposition and evaporation products out of the mould during the stage of pouring.

The actual importance of these problems is reflected in the fact that the application of quality coatings increases production efficiency by producing high quality castings, increased metal yield and eliminate expensive casting operations such as cleaning and machining.

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